Title: Intelligent Monitoring System With High Temperature Distributed Fiberoptic Sensor For Power Plant Combustion Processes

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Abstract

Objectives and Scope:

The objective of the proposed work is to develop an intelligent distributed fiber optical sensor system for real-time monitoring of high temperature in a boiler furnace in power plants. Of particular interest is the estimation of spatial and temporal distributions of high temperatures within a boiler furnace, which will be essential in assessing and controlling the mechanisms that form and remove pollutants at the source, such as NOx.

The basic approach in developing the proposed sensor system is three fold: (1) development of high temperature distributed fiber optical sensor capable of measuring temperatures greater than 2000 C degree with spatial resolution of less than 1 cm; (2) development of distributed parameter system (DPS) models to map the three-dimensional (3D) temperature distribution for the furnace; and (3) development of an intelligent monitoring system for real-time monitoring of the 3D boiler temperature distribution.

Fiberoptic Sensor Development:

Under this task, since the start of the project, our efforts focused on developing an innovative high temperature distributed fiber optic sensor by fabricating in-fiber gratings in single crystal sapphire fibers. A Ph.D. student with the support from a couple of master students under Prof. S. Yin's supervision began work on this project since October 2002. The project is well on track. So far, our major accomplishments include

1) <u>Successfully grown alumina cladding layers on single crystal sapphire fibers</u>. We used 11 nm alumina particles with a purity level of 99.99% and then proceeded to develop a cladding layer on the sapphire fiber core. The main chemicals were a monomer of acrylic acid, an initiator of benzoyl peroxide, and an accelerator of DMPT (N, N-Dimethyl Para Toluidine). In combination with the alumina particles, we were able to successfully form a uniform, protective cladding layer ranging in thickness from four microns to seven microns. Multiple layers could also be grown on top of each other in order to form any required thickness.

2) Successfully fabricated in-fiber gratings in single crystal sapphire fibers. We were able to execute this process by using a photo mask produced via the Photo Chemical Machining Process. A 350 micron period structure was formed with the conventional photolithography process and wet-etching. Such a layer formed a basis for etching the cladding/core with a sulfuric and phosphoric acid (H_3PO_4) solution at around 350˚C.

3) Successfully developed a high temperature distributed fiber optic sensor. We also successfully developed a high temperature distributed fiber optic sensor based on in-fiber gratings fabricated in single crystal sapphire fibers. We used an optical spectrum analyzer to observe resonant peak; and the transmission loss was determined to be quite small. Efforts to improve the coupling efficiency and grating structures are under way. Future research is also planned for improvement in the development of quality, uniform layers of cladding and to test the effectiveness of the fiber at the desired high temperatures. By the end of the first year project (i.e., Sept., 2003), this novel fiber optic sensor will be fully developed.

Boiler Furnace Monitoring Model Development:

Under this task since the start of the project, the emphasis has been on putting into place a computational capability for simulation of combustors. A PC workstation was acquired with dual Xeon processors and sufficient memory to support 3-D calculations. An existing license for Fluent software was expanded to include two PC processes, where the existing license was for a Unix workstation. The graduate student performing this task under Prof. Boehman's supervision began work in January 2003 and has spent the semester learning how to use Fluent for the project. A senior graduate student from another group at Penn State has been available to mentor the new graduate student on specific aspects of using Fluent, such as grid generation to describe the combustors at the Penn State Energy Institute and formulation of boundary conditions within Fluent to describe practical combustion systems. By the summer of 2003, grid and model development will be fully underway.

Intelligent Estimation Theory Development:

Under this task, intelligent state estimation theory will be developed for 1D, 2D, and 3D models and applied to estimate the temperature distribution of furnaces. The validated temperature monitoring models will be used to train the neural network monitoring models off-line. Since the fiberoptic sensors are one dimensional (1D), a theory is being developed which will map the set of 1D (located judiciously within a 3D environment) measurement data into a 3D temperature profile. A graduate student under the direction of Prof. Lee has been assigned to this task. This theory presents a semigroup-based approach to the design and training of a system type neural network which performs function extrapolation. The problem is as follows: given a set of empirical data which originates with some physical process for which the solution and possibly the dynamics are unknown, other than that it possesses a semigroup property, the task is to first form that surface which passes most smoothest and closest through the data points and then to stretch that surface along one coordinate axis. The assumption of the semigroup property suffices to guarantee the existence of a generic mathematical architecture and operation which is explicit enough to support the direct design and training of a neural network. The theory will be tested as realistic physical data generated by the Fluent model becomes available.

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Published Journal Articles, Completed Presentations and Students Receiving Support from the Grant

To date, two refereed conference papers are accepted.

1) S. Yin, S. Nam, J. Charves, C. Zhan, "Innovative long period gratings: principles and applications," Invited paper, to be presented in SPIE annual meeting, San Diego, California, paper number SPIE 5206-10, August, 2003.
2) S. Yin, J. Charves, and S. Nam, "Fabricating in-fiber gratings in single crystal sapphire fibers and its application to high temperature distributed sensing," to be presented in 6th Mediterranean Workshop and Topical Meeting on Novel Optical Materials and Applications, Italy, June, 2003.

Manuscripts to be submitted to the refereed journals are underway. They are expected to be submitted in the summer of 2003.

The following students are involved in the projects:

J.A. Chavez, S.H. Nam, C. Zhan, Melanie Fox, John Valas